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IRRIGATION BY OVERHEAD SPRINKLING

H. A. WADSWORTH[1]

INTRODUCTION

Although the irrigation of truck crops by overhead sprinkling has long been a common practice in some parts of the United States, with some citrus fruits irrigated this way in Florida, the application of water by overhead sprinkling has but recently become a factor in California orchard irrigation practice. Though scattered installations which have been in operation for some years are to be found in various parts of the State, the majority now in operation have been established since 1924.

Irrigation by sprinkling is an attempt to imitate rainfall. Water is carried in pipes under such pressure that when released from sprinkler heads or from perforated pipes, the surface to be irrigated is sprinkled with the coarse drops of a heavy shower. In details, individual installations may differ widely, but in general, the principle is the same. Certain manufacturers of sprinkling equipment recommend distribution from horizontal pipes supported above the surface of the ground and equipped with non-corrosive nozzles or jets at fixed intervals along them. Such an installation can serve a zone of a length equal to that of the pipes and of a width determined by the available pressure and by the number of lines. Other manufacturers recommend rotary sprinklers. When these are used, sprinkler heads somewhat similar in design to revolving lawn sprinklers are so located in the area to be irrigated that the overlapping circles of application completely cover the area.

Sprinkler equipment is relatively costly regardless of the type of distributing system selected. Many installations which are designed to eliminate all labor of irrigation except the opening of a valve or the starting of a pump represent an investment up to $300 an acre. Under favorable conditions, when the operator is willing to handle some portable sprinkling equipment, the initial cost may be reduced to one-half of this amount or less. When natural pressure is not available for the operation of a sprinkler installation, pumps must be included in the plan. In such cases the first cost of the system will be increased by the cost of the pump with its fittings, and the annual

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cost will be increased by the carrying charges on this additional investment and by the cost of the power consumed.

Because of the large investment represented by sprinkler equipment, the practice of overhead irrigation has been mainly limited to the irrigation of high-value crops on high-priced land. In California, numerous plantings of oranges, lemons, avocados, and nursery stock are being irrigated by this method. Sprinkling is often practiced in truck-growing areas where soil, market facilities, and climatic conditions warrant the expense involved. Because of the flexibility of the system and the possibility of irrigating small tracts efficiently with a minimum of labor, overhead irrigation is rapidly finding favor with poultrymen as a means of watering chicken runs and of irrigating small areas for green feed. The method is also sometimes used for the irrigation of lawns and ornamental shrubs.

OVERHEAD SPRINKLER LINES

Sprinkler installations for the irrigation of orchards, nurseries, and truck gardens fall into two general classes: perforated overhead pipes, sometimes called overhead nozzle lines, and revolving sprinkler systems which water circular areas.

The distribution of irrigation water in the form of small jets forced through openings in the shell of the pipe was the first method used. In these early installations a few lengths of pipe were perforated and the water forced through them by a simple hand force pump. Since these perforations were not reinforced with non-corrosive metal, the holes gradually became irregular in shape or entirely clogged.

Modern sprinkler lines carry patented nozzles of non-corrosive material. These are screwed into tapped holes drilled through the shell of the pipe. The holes through these nozzles are intended to be so shaped that particles of rust, which may be carried through the pipe, cannot clog them. It is extremely important that the nozzles in a pipe line be set in a straight row. Special drilling machines have been designed to facilitate this.

LOCATION AND DESIGN OF NOZZLE LINES

A strip of land 50 feet wide can be irrigated from a single overhead line if that line be so arranged that it can be rotated through a turning union and the angle of the jets changed. When the angle of the jet is 45 degrees above horizontal, greatest distance is secured. Hence, the total angle available in the turning union should be 90

degrees. Considerable attendance is required with installations of this sort if changes in angle of jet and consequently in the area served are made by hand. Turning machines consisting of small turbines, driven by the flow of water in the vertical supply type, have been devised. These attachments slowly turn the pipe line through the required angle. Need for personal attendance is practically obviated by the use of this device.

The details of the installations vary widely with the proposed use. For truck crops and ornamental plantings the pipes may be carried on short posts, or even laid on the ground. When the pipes are carried on posts, these supports are usually about 15 feet apart. When longer spaces are used, it becomes increasingly difficult to turn the line because of its sag. Simple roller bearings can be secured which may be placed on the posts as an aid to easy turning. For short lines the bearings may be eliminated and the lines held in place by metal straps over the tops of the posts. Even in good installations with abundant pressure, lines longer than 700 feet are not to be recommended.

Many growers object to the obstruction to cultivation which results from placing sprinkler lines on short posts. Posts carrying the pipe lines about six and one-half feet above the ground permit the passage of men and horses under the lines and eliminate most of this trouble. Four by four inch redwood posts make suitable supports for sprinkler lines. They should be long enough to be set in the ground 2½ or 3 feet and should still give a 6½ foot clearance. When greater permanence is required, sections of 1¼-inch or 1½-inch iron pipe set in concrete footings may be used.

Obstruction to cultivation can be still further reduced by the use of high poles which may be from 100 to 200 feet apart. The nozzle line is then suspended from a wire cable which joins the tops of these poles and hangs in the form of a catenary between them, the wires supporting the nozzle lines carrying specially designed galvanized iron hooks equipped with simple roller bearings at their lower ends. The nozzle lines fit into these hooks and can be brought to the proper height by adjustment of the wires leading from the supporting cable.

Because of unavoidable sag in the cable, the height of the poles supporting it should be considerably greater than the height required for the nozzle line. Suitable poles can be made from standard telephone poles having a diameter of 8 to 10 inches at the base and 6 to 8 inches at the top. These poles should be set in holes at least 6 feet deep and should be tamped firmly in place. For greater permanence, footings of concrete may be used. Since any deflection of the high posts from their original position would result in a further sagging

of the cable and a consequent distortion of the nozzle line, it is well to anchor the end posts with guy wires fastened to "deadmen." These "deadmen" may be any massive concrete or wooden members buried 3 or 4 feet below the surface and attached to an anchor rod which terminates in an eyebolt above the surface. The "deadmen" should not be closer to the base of the pole than a distance equal to one-third its height. Guy wires attached to these anchor rods by means of turnbuckles give rigid support for the poles. Future sag in the line can be corrected by the turnbuckles.

The weight of the cable to be used depends upon the spacing of the poles, the length of the pipe line to be supported, and the pipe sizes which make up that length. Most manufacturers who produce sprinkling equipment of this sort maintain an engineering office where information as to the suitable spacing of poles and the required cable sizes can be secured. When such advice is not available, an engineer familiar with sprinkling systems should be consulted and his advice followed. No detailed design of sprinkler lines can be given which would be suitable for common use, since each installation must be considered individually before an intelligent design can be offered. In general, the nozzle lines should be at right angles to the supply lines and should run the long way of the area to be irrigated, in order that obstruction to cultivation may be minimized. If the pipe sizes making up the nozzle lines are wisely chosen, and if sufficient pressure is available, the lines may be as far apart as 50 feet, if necessary to secure a better location in the field.

The pipe sizes to be used for overhead sprinkling lines depend upon the type of nozzle used, the pressure available at the intake of the line, and the distance between nozzles.

As has been stated above, the overhead sprinkling line finds its greatest popularity in nursery work, truck growing, and ornamental planting. The oldest installations in California were of this type and were the first ones used for the irrigation of citrus trees. The practice of overhead sprinkling did not spread among citrus growers, however, because of the obstruction offered to cultural practices by the supporting posts. Horizontal lines have also proved a great inconvenience in the handling of fumigation tents. Furthermore, it is probable that the fine stream issuing from a nozzle of the type used on such lines increases evaporation loss. Figure 1 shows a typical overhead sprinkler line in operation.

FITTINGS FOR NOZZLE LINES

In addition to the special brass nozzles which are essential to satisfactory operation of a sprinkler installation of this sort, there are other fittings which reduce difficulties of installation and make for greater convenience in operation. Automatic turning equipment has already been mentioned, as has also the simple roller-bearing saddle, in which a long length of pipe may rest and still turn easily. The saddle is supplied with several base fittings for use with various methods of support for the sprinkler line. Turning unions completely

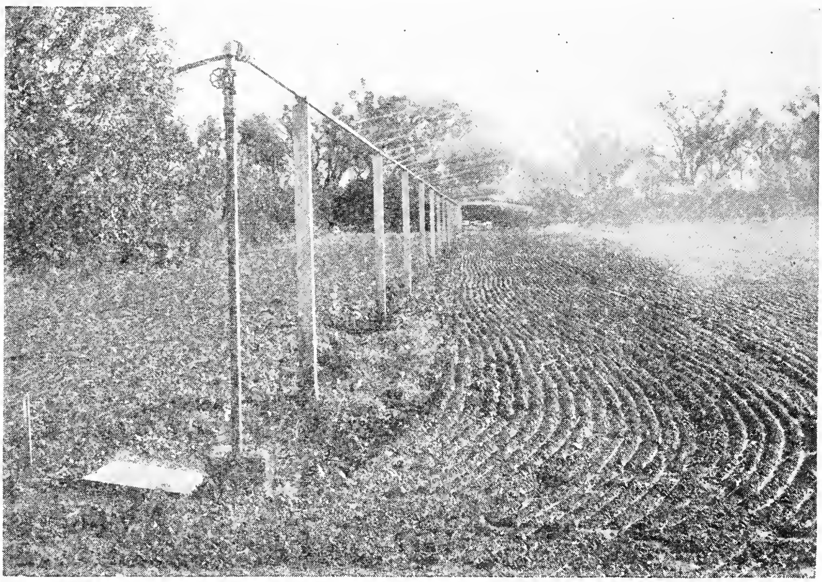

Fig. 1.—General view of overhead sprinkler line. Sprinkling from a perforated horizontal pipe, which may be rotated through a turning union, is a popular means of applying water to ornamental plants, vegetables, and poultry runs.

assembled are sold by manufacturers of sprinkler equipment. Ordinarily a perforated conical strainer is built into the union so that water entering the nozzle line may be kept free from dirt, which might clog the fine nozzle openings. For extensive installations where several parallel lines are to be turned in unison, the power supplied by the turbine of the automatic turning equipment is inadequate and hydraulic oscillators may be obtained in that case. The reciprocating action of the central oscillator is carried to the turning unions which are operated by carefully balanced cables.

Flushing valves are usually installed at the end of each nozzle line to permit the removal of dirt and scale from the line without the necessity of dismantling.

Difficulty is often experienced in assembling sections of drilled pipe since the couplings must be tight and the nozzles in the several sections in perfect line. The use of quick-acting couplings with squared sockets makes it impossible to assemble the pipe unless the nozzles in the several sections are in perfect alignment.

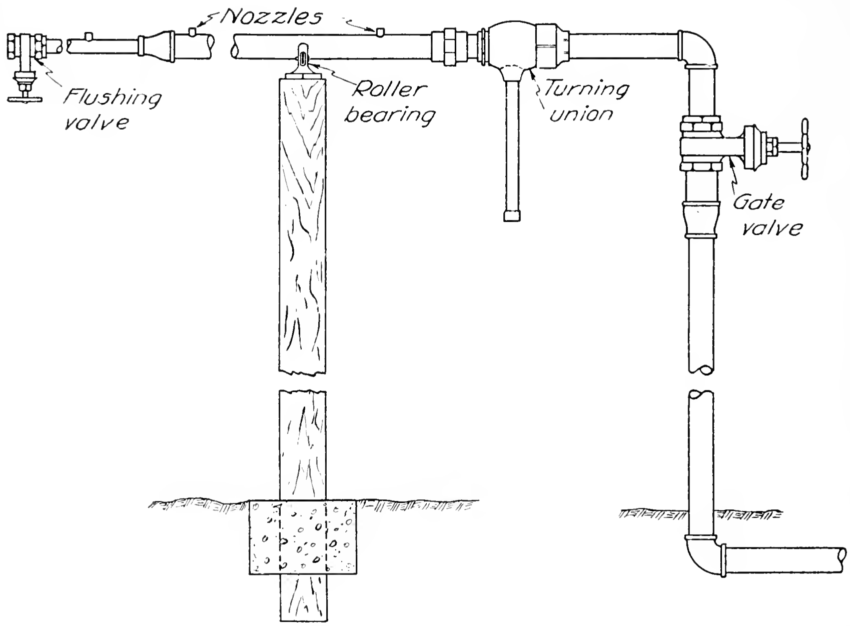

Fig. 2.—Detail of typical sprinkler line assembly. The special fittings required for the installation of overhead sprinkler lines can be secured only from manufacturers of sprinkling equipment.

Other equipment such as gate valves, couplings, tees, and unions, which may be necessary for assembly, is common to all pipe work and need not be considered. Figure 2 shows the detail of a sprinkler line assembly.

WATER REQUIRED FOR OPERATION

For outdoor irrigation, with nozzles spaced on 3-foot or 4-foot centers, a supply of one gallon per minute for every 15 feet of line should be provided. With uniform application over a strip 50 feet wide, such a flow would provide an irrigation of one inch in about eight hours.

PRESSURE REQUIREMENTS

A pressure of from 25 to 35 pounds per square inch is required at the head of a nozzle line for satisfactory distribution. In cases where this pressure is not available or where it cannot be created without prohibitive cost, special nozzles should be used which are designed for low pressure operation. Planning such a low pressure system is a special problem which should be undertaken only under advice from a reliable manufacturer of sprinkling equipment of this sort.

When the sprinkler lines are remote from the source of pressure, much more pressure is required at the source than can be used at the intake end of the nozzle line. Pressure is always consumed when water is forced through a pipe line. This loss results in the necessity of overcoming the resistance to flow, which is offered by the relatively rough interior and small diameter of the supply pipe. The amount of pressure necessary to overcome this friction varies with the amount of water carried, the length of the line, the size of the pipe, the material of the pipe, and its age. Methods of determining the pressure consumed under given conditions will be discussed under a consideration of the design of supply pipes.

REVOLVING SPRINKLER SYSTEMS

As has already been indicated, sprinkling heads cannot distribute water over a given rectangular area as uniformly as a well operated sprinkler line because of the overlap of the circles of application which are necessary to insure complete coverage. With field crops, nursery plantings, and truck crops, where the location of sprinklers is not rather rigidly fixed by planting arrangement, part of this objection can be obviated. When sprinkler heads can be located on a hexagonal pattern and every head placed at an equal distance from every other head adjacent to it, only about 15 per cent of the area served will be within the zones of overlap, provided the spacing is properly determined according to the spread which may be expected from a single head. In cases where the location of the heads cannot conform to a true hexagonal spacing because of the planting scheme—or for some other reason—the amount of overlap must be increased if complete coverage is provided. No real objection is offered by this necessary overlap, since all sprinkler heads throw less water to the extreme circumferance of the circle of coverage than is applied to the

central area. The overlap tends to equalize any lack of uniformity of application which may result from a single head.

Many commercial sprinkler heads now on the market throw water with fair uniformity over a circle with a 60-foot diameter when a pressure of from 15 to 18 pounds per square inch is available at the head. With an expected diameter of coverage of 60 feet, sprinkler heads should be located so that each head is 52 feet from its neighbors in every direction. Such a spacing can be effected by staggering the sprinkler heads on feed lines which are parallel and which are 45 feet apart. This plan of installation is evidently impossible in orchards that are planted on the rectangular system. Several plans of layout are shown in figure 3. In this figure, plan A is a hexagonal installation for truck gardens, nurseries, or for orchards planted on the hexagonal plan. Plans B, C, and D are superimposed upon rectangular orchard plantings.

LOCATION AND COST OF SPRINKLERS IN PERMANENT PLANTINGS

In orchards set on the rectangular plan, with 24-foot spacings, a close approximation to the ideal installation suggested above can be reached by establishing sprinkler heads in alternate trees in alternate rows. When such a scheme is adopted, the diameter of a single circle of coverage must be two and one-half times the distance between trees, if complete coverage is to be obtained with a minimum of overlap. Under the condition given the diameter of coverage required for most efficient distribution is 60 feet.

Some growers object to locating heads directly over a tree. The accumulation of excess water at the trunk of the tree, because of unavoidable leaks in the sprinkler heads and the difficulty of handling fumigation tents over trees equipped with sprinkling stands, are given as criticisms of this method. Growers who disapprove of such an arrangement sometimes install sprinklers in the centers of the tree squares. The diameter of coverage required is the same in either case. Some obstruction to cultivation must be caused by an installation in which the sprinkler pipes rise from the centers of the tree squares.

Some types of sprinkler heads are designed for greater coverage than the 60-foot diameter usually served by the more common heads. It is difficult to use these special heads advantageously in orchards on common spacings, because of the unavoidable overlap which must be allowed to obtain complete coverage. If sprinkler heads are placed in every third tree in every second row, the circle of application from a single head must have a diameter equal to about three and one-third

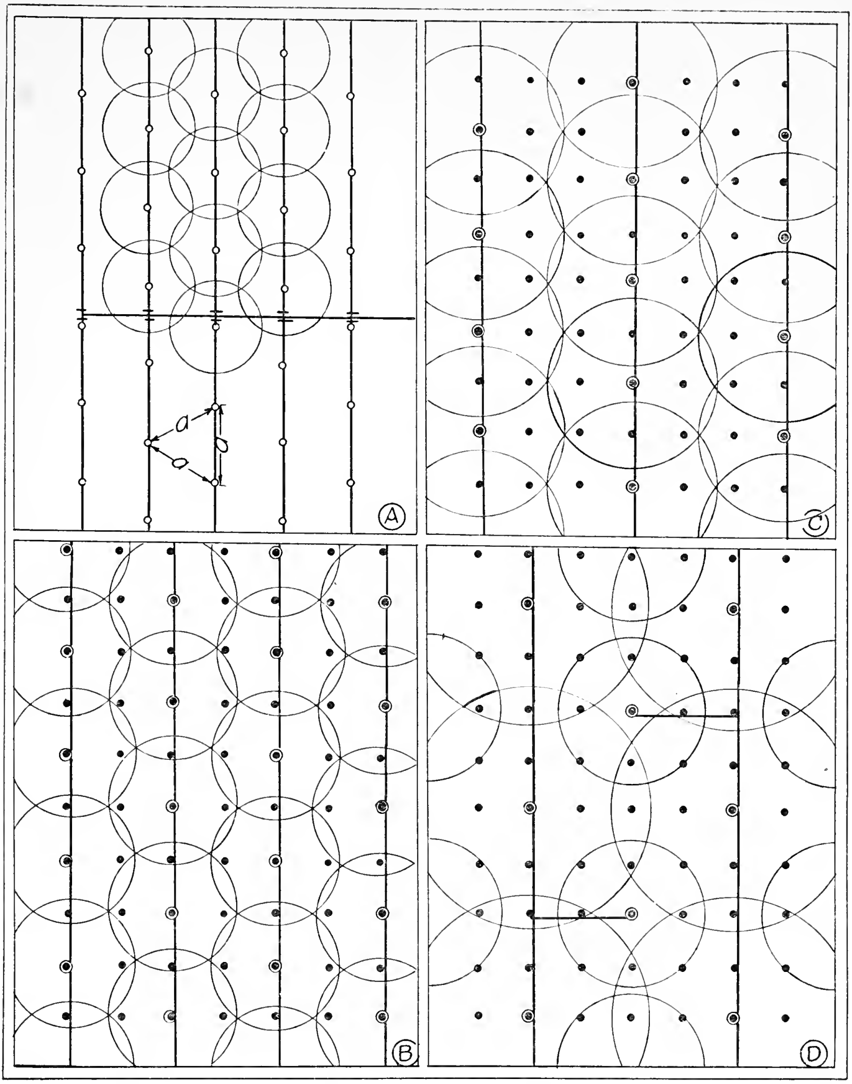

Fig. 3.—Typical layouts of permanent sprinkler installations.

A. A hexagonal installation reduces the overlap of circles of coverage to a minimum. Each head is the same distance from its neighbors in every direction. Such a method of installation is not adapted to orchards on a rectangular planting plan.

B. A common method of installation in rectangular plantings is to establish a sprinkler head in every second tree in every second row. The sprinkler heads are not equally spaced.

C. Economy in underground piping results when individual sprinklers can be located in every second tree in every third row. The distribution is lacking in uniformity.

D. When sprinklers of large diameters of coverage are used auxiliary sprinklers are sometimes installed to insure complete coverage without excessive overlap.

times the distance between the trees. With trees planted on 24-foot distances, for example, the diameter of application required would be about 80 feet, and undesirable inequalities in application would necessarily result.

Some manufacturers, particularly those who specialize in sprinkling devices for golf greens, offer sprinklers with great diameters of coverage for orchard use. The advantage in using such heads lies in economy in underground piping. The great disadvantage is that undesirable inequalities of distribution must exist if the sprinkling heads be located with respect to existing tree rows. In some installations with large-diameter heads, a dry area is allowed to remain between the circles covered by four large sprinklers. This dry area is covered by a small sprinkler fed from a lateral leading from the nearest main.

TYPES OF SPRINKLER HEADS

Sprinkler heads designed for orchard work fall into four main classes, as follows:

(1) Solid heads carrying no moving parts. With these, water is broken into drops by impact against a baffle plate in the top of the head. The drops are forced through ports in the top or side of the head by the pressure in the line. Such heads usually serve areas of small diameter, their advantage being that they have no moving parts, which eventually necessitate replacements, and that there is freedom from leakage when in operation.

(2) Rotary sprinklers carrying small and simple moving parts. These throw water over a greater distance than could be served by a solid head. This wider distribution may be due either to the impact of a revolving member against the jet, or to the centrifugal action imparted by short arms. The pressure of the water in the riser revolves the moving parts. Such heads usually have a greater capacity than solid heads and usually cover a larger area. Some heads in this class carry a thrust bearing, which is subject to wear. When this wear becomes appreciable, the head leaks and the leakage runs down the stand pipe, causing an undesirable accumulation at the base. One manufacturer of a popular head in this class provides a simple ball-bearing to accommodate this thrust with a minimum of wear.

(3) Long arm sprinklers depending on centrifugal force for the distribution of water. Arms of brass or galvanized iron pipe are screwed into specially designed heads, which screw on the riser pipes. These heads contain thrust bearings, usually of babbit or monel metal against brass. The arms are bent near their outer ends so that they

form a slight angle with the diameters of the heads, as indicated by the longer sections of the arms. When water is forced through these arms, the reaction to the issuing stream causes the heads to revolve. Caps of special design are screwed to the ends of the arms to promote uniform distribution. In many cases the cap of one arm carries a round hole which throws a solid jet to the extreme circumference of

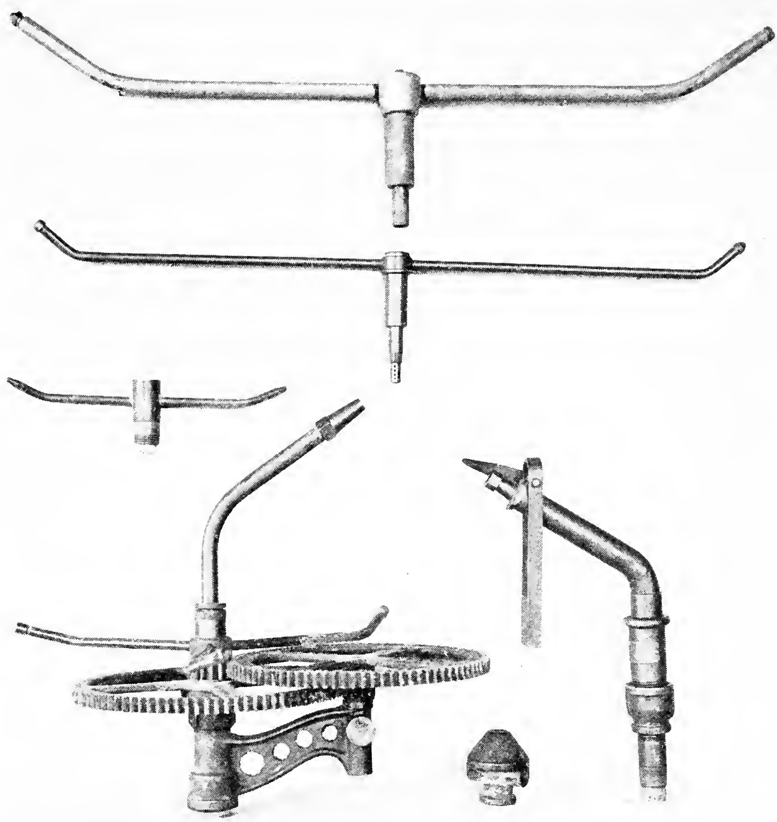

Fig. 4.—Types of sprinkler heads. Sprinkler heads should be selected after consideration of the required diameter of coverage, the capacity of each head under the available pressure, and the water supply.

the wetted circle. The other end sometimes carries an aperture of such design that a fan-shaped jet is provided, which serves the inner zones of the area. When the arms of such sprinklers are of galvanized iron pipe, the bending to form off-set ends may result in scales of rust which may lodge in the discharge orifices and stop the head.

(4) Geared sprinklers, designed to secure greater coverage than can be obtained by the common long arm type. This end is achieved

by having part of the water escape through a central jet of such design that a large throw can be obtained. The remaining water is sent through a rotary sprinkler head which supplies the inner zones of the area. The rapid revolution of this rotor moves the large central jet by means of a more or less elaborate gear train so that the whole circumference can be served. Many sprinklers in this group are adjustable so that varying quantities of water can be sent through the central jet. Increasing the quantity discharged through the central jet makes for increased application on the circumference of the circle of coverage and a lighter application near the center. Several sprinkler heads in common use are shown in figure 4.

UNIFORMITY OF COVERAGE FROM REVOLVING SPRINKLERS

An ideal sprinkler head should apply water uniformly over the diameter of coverage. While this ideal cannot be reached, it has been approximated closely by several modern sprinklers. When many sprinklers are to be used for the irrigation of a large rectangular area, a slight "feathering out" in the uniformity of application near the circumference is not a great disadvantage, since the overlap of these circles of coverage occurs on the zones of lighter application and tends to equalize them.

Many observations have been made in an effort to determine the uniformity of application resulting from standard sprinkler heads of modern design. Except for solid heads, which are not widely used in orchard practice, all sprinkler heads are, to some extent, adjustable. Any adjustment tends to influence the uniformity of distribution. Light rotary heads can be adjusted by a slight constriction in one or all of the small tubes through which water is discharged. A slight bend in the soft metal of these tubes also affects the uniformity of distribution.

Long arm sprinklers can be adjusted in two ways. One method is to change the terminal orifices. Most manufacturers send long arm sprinklers into the field with an assortment of brass outlet fittings to be used on the ends of the arms. Changing a large holed fitting for a small one results in increasing the application on the circumference. Equipping both ends of the arms with such orifices in place of fitting one end with a notched or diamond-shaped orifice results in excessive application on the circumference and almost no application near the center. Long arm sprinklers can also be adjusted by backing the arms out of the head so that the angle formed by the offset in the arm

with the horizontal may be changed. If, however, the arms are backed out so far that the plane described by the main part of the arm and the offset is vertical, there can be no revolution and consequently no distribution.

As has been indicated, geared sprinklers can be adjusted by changing the proportion of the whole flow which passes through the central jet. This can be done by the manipulation of a needle valve behind the central jet, if one is provided, or by changing the brass orifice cap which covers the jet.

Changes in the pressure under which a head is operating may affect the uniformity of distribution resulting from that head.

For these reasons it seems unnecessary to give results obtained from distribution tests. In most cases heads must be adjusted after installation to accommodate minor and perhaps unintentional changes in the head itself and to adapt the head to the pressure available at the particular location. Tests for uniformity can be easily made in the field. In making such a test cans of uniform cross-section are placed at equal distances along one radius of the circle to be covered. At the end of a given period, absolute equality of distribution is reflected by equal depths in the several cans. Such a test should be run for several hours before reliable conclusions can be reached. A refinement of this method lies in catching the water in funnels established at equal distances along a radius and collecting the drainage water from such funnels in glass test tubes of equal diameters. Minor inequalities of distribution are more quickly and accurately detected by this method. A day with little or no wind should be chosen for such tests, since a very slight breeze will result in a great distortion from the normal coverage.

PRESSURE REQUIREMENTS FOR REVOLVING SPRINKLERS

Since the pressure under which a sprinkler head operates affects its uniformity of distribution, recommendations as to suitable pressures should be closely adhered to. Most solid and rotary sprinklers operate effectively under a pressure of 15 pounds per square inch at the head. Long arm sprinklers require more pressure for successful operation than solid heads. Geared sprinklers ordinarily require more pressure for operation than sprinklers of any other type because of the mechanical losses in the gear train. Large geared sprinklers, such as are used for the irrigation of parks or golf greens, are sometimes designed for operation under pressures as great as 100 pounds per

square inch. Manufacturers claim a diameter of 175 feet for the circle of coverage of geared sprinklers under such pressures. The pressures recommended by manufacturers are usually those required at the heads. Gages should be installed at the top of the standpipe and immediately beneath the thrust bearing, if the actual pressure under which a head is operating is to be measured. If such a location is impracticable, a gage may be installed nearer the ground. If this is done, the reading on the gage should be reduced by as many pounds as is represented by the height of the sprinkler above the gage, divided by 2.31. This reduced pressure will closely approximate the pressure at the head.

CAPACITIES OF SPRINKLER HEADS

Sprinkler heads vary widely in capacities. This is due partly to differences in design and partly to the pressures for which various heads may be recommended to insure greatest uniformity of distribution.

For heads commonly used for orchard irrigation, such as rotary sprinklers and certain types of long arm sprinklers, a discharge sufficient to cover the circle of coverage to a depth of one inch in four or five hours may be considered as typical. Geared sprinklers may, and usually do, discharge more than that indicated above. Solid heads of various makes differ widely in discharge under operating pressures.

Since knowledge of the amount of water discharged by a single head is of great importance in the design of a sprinkler installation, tests have been run on a few modern heads under varying pressures.

A solid head popular in the citrus areas of the southern states was found to discharge 7.6 gallons per minute under a pressure of 35 pounds per square inch. Under a pressure of 20 pounds per square inch, the discharge dropped to 5.9 gallons per minute, and 10 pounds gave only 3.8 gallons.

Two makes of long arm sprinklers in common use in California showed almost identical capacities for similar pressures. These heads discharged 6.9, 5.3, and 3.8 gallons per minute when operated under pressures of 35, 20, and 10 pounds per square inch, respectively.

As has been stated, geared sprinklers have greater capacities than either solid heads or long arm sprinklers. One geared sprinkler used in parks and on golf greens discharged 17.3 gallons per minute under a pressure of 35 pounds per square inch. Under pressures of 20 pounds per square inch and 10 pounds per square inch, the discharge was 13.4 and 9.4 gallons per minute, respectively.

When the discharge of a certain head under the recommended pressure is known, the time required for an application of one inch of water can be readily computed by the following simple formula:

If $D =$ diameter of the wetted area in feet, and

$G.P.M. =$ capacity of the head in gallons per minute, then

$$\frac{D^2}{G.P.M. \times 122} = \text{hours run required for an application of one inch on the wetted zone.}$$

This equation is based upon the assumption that evaporation losses are negligible.

Fig. 5.—Rotary sprinklers in operation. Permanent installations represent a high first cost and are most popular in high producing areas.

TYPES OF INSTALLATIONS FOR USE WITH REVOLVING HEADS

Permanent Sprinkler Installations.—Installations which are provided with fixed riser pipes connected to underground laterals, are sometimes called permanent sprinkler installations. Such an installation is shown in operation in figure 5. With this type it is possible to irrigate an entire field or any part of it by an adjustment of the valves which are at the intake ends of the laterals and in the individual riser pipes. The number of sprinklers that can be carried by a single lateral, the capacity of each head under the available pressure, the topography of the area to be served, and, in some cases, the head of water available are factors which affect the design. Since these considerations vary widely in different areas, it is inadvisable to copy an existing successful installation unless it is definitely known

that conditions are similar. Every problem of permanent sprinkler design is a special problem which must be undertaken only after the governing factors are known. A typical plan for a permanent installation is shown in figure 6.

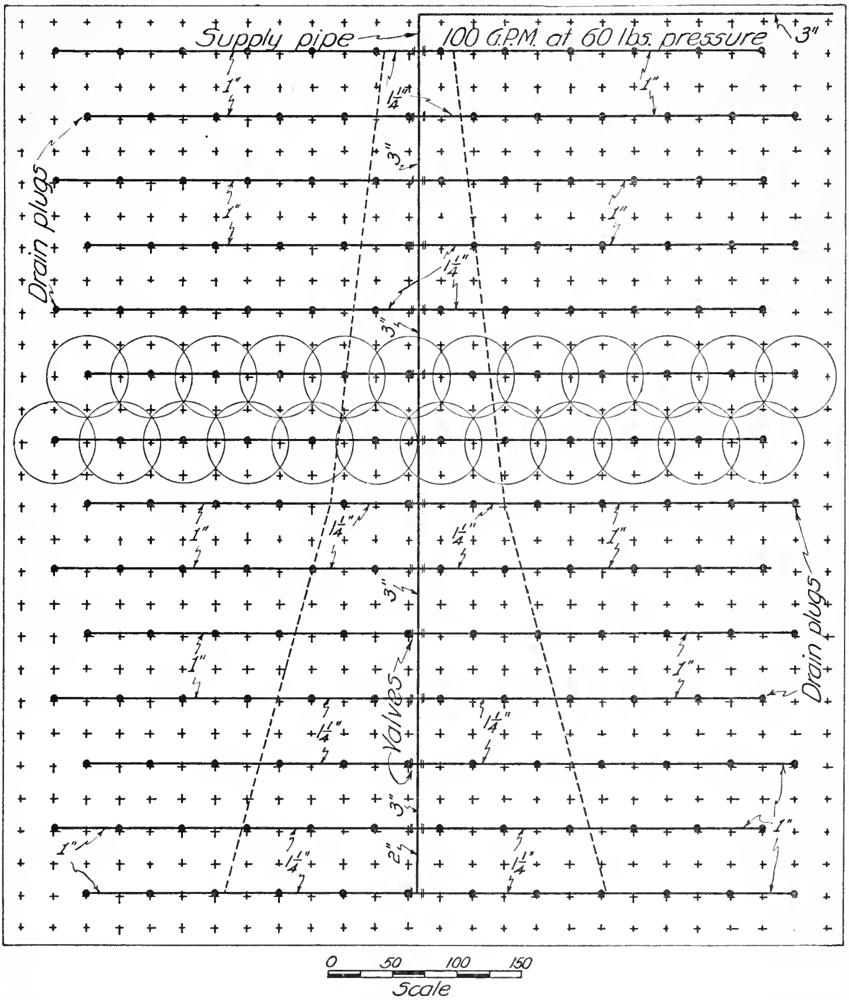

Fig. 6.—Typical plan for permanent installation. The pipe sizes indicated above are suitable only for the conditions indicated and for installations in which both main and laterals are level. The dotted lines indicate the point at which 1-inch pipe must change to 1¼-inch pipe. Every installation is a special problem and must be so considered. The circles represent coverage and indicate the extent of overlap.

It is evident from the consideration of the location of sprinkler heads, that laterals in the case of permanent plantings must be installed adjacent to alternate rows in the grove, if heads giving

common diameters of coverage are to be used. Risers, capped by sprinkler heads, start from tees located on the laterals below alternate trees. A fair approximation to ideal distribution can be obtained in this way.

Six sprinkling heads on a single lateral are commonly used with sprinklers of ordinary capacities. A 10-acre area of usual shape (⅛ mile square) can be satisfactorily irrigated, if a main pipe line runs through the center of the tract and if laterals branch to each side from crosses installed on the main opposite the selected tree rows. Each lateral on a 10-acre tract must carry six risers to insure complete coverage. It is customary to consider larger areas as multiples of such units. In such a case, the main mentioned above would become a lateral of the larger installation, while the laterals would become branches from laterals of the larger installation. Since available water and available pressure can rarely be developed for the simultaneous operation of more than 10 acres, the multiple installations suggested above are very rare.

One of the advantages of overhead sprinkling as a means of applying irrigation water is the flexibility of the method. Localized areas of light soil can be irrigated frequently and lightly, while the heavier soils can be watered heavily and more infrequently. Valves located at the heads of laterals supplying water to heavy soils make it possible to cut out these areas when water is required by lighter soils under the same unit. Globe valves may be used for this purpose, although simple cut-off valves are suitable, since the valve will usually be entirely open or entirely closed. The valve in either case will be below the surface of the ground, since it must be installed on the underground lateral. It should be protected by a short length of casing which ends at the surface of the ground or slightly above it.

It is practically impossible to select pipe sizes for a lateral with such exactness that each riser on that lateral will be supplied with the pressure required for best distribution. A small valve is usually installed on each riser so that pressures may be equalized and each sprinkler head supplied with the specified pressure. In some cases a special fitting, carrying a valve and a strainer, is incorporated in each riser at a convenient height. This fitting is so designed that the strainer can be cleaned of scale accumulation and other débris in the water without dismantling the riser assembly. Such fittings also provide a convenient point at which the riser may be temporarily removed if it interferes with fumigation. Figure 7 shows a riser pipe equipped with a strainer and valve fitting.

In other installations, a strainer is built into the head. Such a design may entail the use of a ladder when the strainer is to be cleaned.

Fig. 7.—Detail of permanent riser assembly. The offset fitting carries a strainer and a valve by which inequalities of pressure can be accommodated. The riser can be dismantled at this fitting for cleaning or replacement.

Some means of draining the pipe system should be provided. Repairs and replacements can best be made on empty lines. In areas where freezing weather is to be expected, lines should be drained.

Drain plugs should be installed at the end of each lateral and at the end of the main, if local conditions would cause an accumulation of water at that point. Common plugs screwed into terminal couplings provide a cheap and satisfactory means of drainage. In cases where the laterals run up hill from the main, the drain plug should be installed in a tee connected by a short nipple to the discharge end of the cut-off valve on that lateral.

The design of a satisfactory sprinkler installation is complex and requires considerable familiarity with the principles involved in the flow of water in pipes. Some discussion of the design of sprinkler layouts and a friction head table for iron pipe of small diameters is furnished in this circular as an aid to those who are removed from the service furnished by manufacturers of sprinkling equipment.

As may be suggested from the list of materials required for a permanent sprinkler installation, the cost of such a system is high. Under average conditions, when tree rows are from 20 to 24 feet apart and when sprinkler heads are located in alternate trees along these lines, a cost of $300 an acre is not unusual. This cost is based upon pipe prices obtained in the spring of 1925. When truck crops or nurseries are to be irrigated and a more efficient location of sprinkler heads is effected, this cost may be slightly reduced. Iron pipe has the unfortunate property of an ever decreasing diameter due to the formation of scale within the pipe. This property is apparent even when pipes carry only the purest water. If an installation is planned for a 20-year life, pipe sizes which will have ample capacity during the whole period should be chosen. A layout based upon the capacities of new pipe might be considerably cheaper than the estimate given above. The estimate of $300 an acre is based upon a design in which the capacities of pipes ten years old are considered.

Portable Sprinklers Operated from Underground Laterals.—Many growers are prohibited from using a permanent installation because of the high first cost or because of unwillingness to accept the high annual overhead charge which such an installation would entail. The use of portable stands attached by ¾-inch garden hose to outlets carefully located on an underground distributing system provides for the convenience and benefits of overhead sprinkling without the high first cost of a permanent installation.

There is no standard design for portable sprinklers. In most cases growers build sprinkler stands from materials at hand and cap them with purchased sprinkler heads. In some cases the riser pipe is mounted on a light wooden platform by means of a bend elbow. Guy wires run from the corners of the stand to the top of the riser. A tee

or elbow fitted with a hose-thread adapter, allows for the connection of a supply hose. Another common type is made entirely of pipe sections and fittings. A ¾-inch pipe cross, fitted with 3-foot lengths of ¾-inch pipe, furnishes the base. The riser pipe starts from a tee connected to one arm of the cross by a short nipple. Three of the arms from the cross are sealed by caps, while the fourth is fitted with a hose thread-adapter which allows the entrance of water. Guy wires

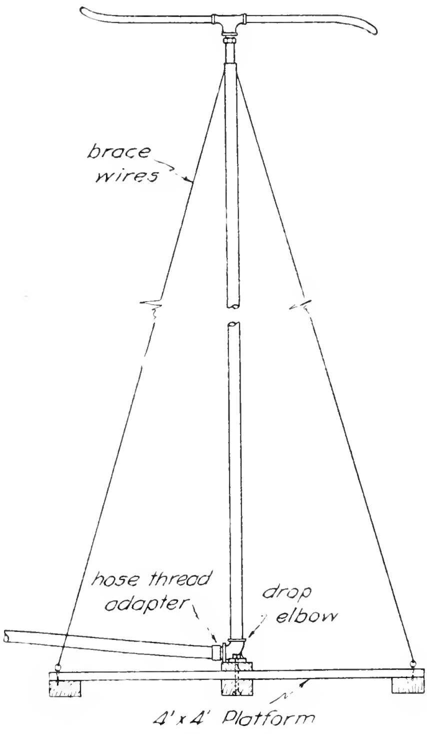

Fig. 8.—Detail of portable sprinkler stand. Such stands are usually home-made except for the sprinkler head. The use of a drop elbow at the base of the riser pipe simplifies the connection with the supply line.

are essential for all types of portable stands. Figure 8 shows a satisfactory design for a portable sprinkler stand. Figure 9 shows such stands in operation.

Hose lengths used to connect portable stands to underground outlets should be less than 50 feet long because of the great pressure losses in such material. When the hose is in use short bends should be avoided. Hose is at best short lived and should be carefully drained, coiled, and stored in the shade between irrigations.

It is evident that economy in underground piping can be effected by the use of portable sprinklers operated by hose lengths of 50 feet.

Such underground laterals are ordinarily placed under every fifth or sixth tree in the grove. The outlets are usually short risers, connected to the underground lateral by means of tees, and capped by

Fig. 9.—General view of portable sprinklers in operation. The use of such portable sprinklers reduces the first cost. Flexibility in operation can be gained by the use of such an installation.

common garden faucets equipped for hose couplings. Trees sheltering such outlets are often flagged in some way, to insure prompt identification during irrigation.

Another saving resulting from the use of portable sprinklers as compared with permanent installations is in the initial investment in the risers and sprinkling heads. Long arm sprinklers which throw relatively large quantities of water are ordinarily used on portable

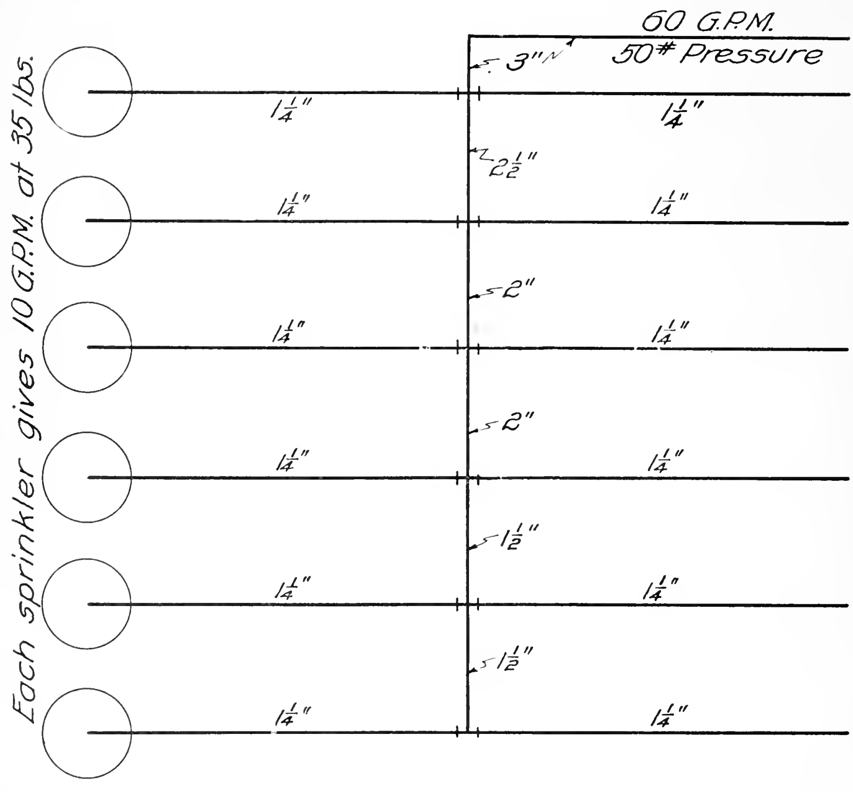

Fig. 10.—Suggested design for underground pipe system under assumed conditions of available supply and pressure. Each sprinkler is operated from a separate lateral. Note the economy of smaller pipe necessary in this scheme of installation as compared with that shown in figure 11.

sprinklers. Six portable sprinklers are usually operated at once, and only that number need to be provided for the usual 10-acre installation. Economy can be gained by designing the underground pipes so that each lateral carries but one sprinkler, rather than by locating all the sprinklers along one lateral and finishing the zone within reach of that lateral before the next is begun. With the latter plan of distribution, the first section of the lateral line must be of sufficient

size to accommodate the water supply necessary for the five sprinklers below it in addition to that used by the first. A further saving results in possible reduction in the diameter of the main supplying these laterals, since the required capacity of the main is reduced at each turnout. Figures 10 and 11 illustrate the saving which may be effected by this design.

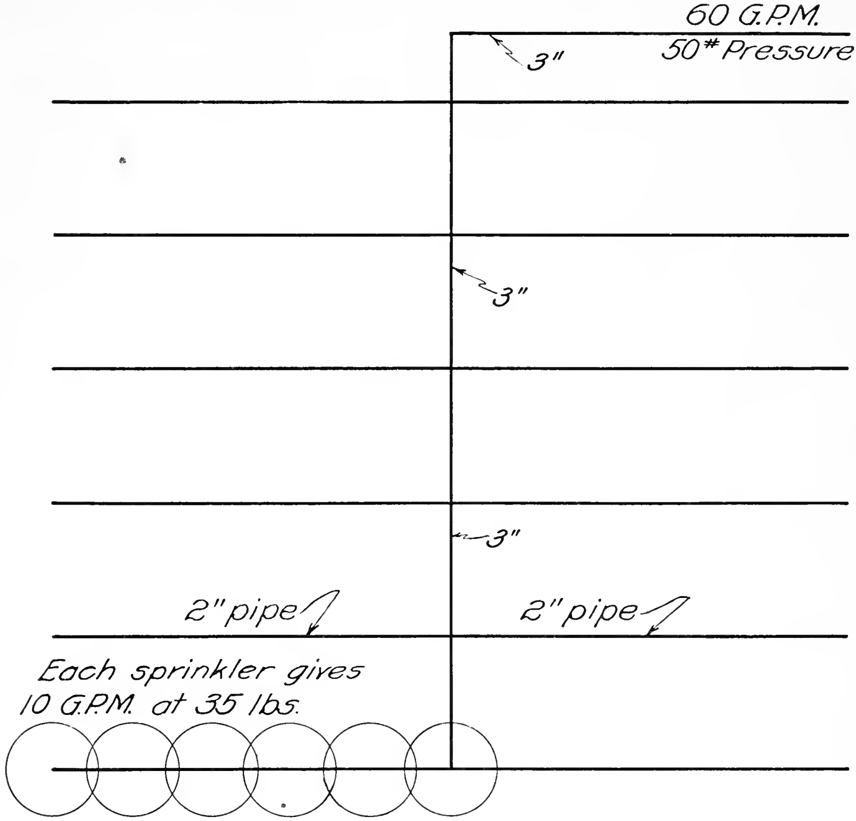

Fig. 11.—Suggested design for underground pipe system for use with portable sprinklers when each lateral must have sufficient capacity for the simultaneous operation of six sprinklers.

Except for the drain plug required at the end of each lateral, few fittings are needed for a sprinkler installation of this type. Valves regulating the flow into the laterals may be eliminated; pressure adjustment into individual sprinklers may be effected by manipulation of the garden faucet serving the stand.

Portable installations of this type represent an investment of about $100 an acre, including the cost of the portable sprinkling stands. Isolated installations in which secondhand pipe has been used are estimated by the owners to have cost even less.

Portable Sprinklers Operated from Portable Surface Laterals.—A further decrease in cost can be effected by the use of portable laterals in place of the underground laterals used in permanent installations. Such installations are neither popular nor common, since the saving in cost by using them is, to a great extent, offset by the increased labor cost of operation.

A main underground line of sufficient size to carry the quantity of water required for the operation of the portable stands is laid on the long axis of the area to be served. This line is equipped at intervals of about 100 feet with risers capped by 2-inch hydrants fitted for connection to 2-inch rubber hose. A short length of such hose furnishes a flexible connection between the hydrant and a portable lateral of 1½-inch pipe, which is assembled on the surface of the ground and which extends down the center of the zone to be served. The sections of pipe which make up the surface lateral are fitted at intervals of about sixty feet with ¾-inch garden faucets. Portable stands are connected by means of hose to these outlets in the surface lateral, and a zone as long as the lateral and as wide as can be reached by the length of hose used, is irrigated before the lateral is moved. When one zone is completed, the surface lateral is taken apart, carried to a position opposite the next riser on the main, and reassembled.

It is evident that the economy of pipe design which is possible if each lateral carries but one sprinkler cannot be effected with installations of this type. The main must be large enough to carry the entire flow to its end; since there is but one lateral, it must be large enough to carry all the sprinklers.

DESIGN OF SUPPLY PIPE SYSTEMS FOR SPRINKLER INSTALLATIONS

Because of its closely limited cross-section and the roughness of its bore, iron pipe offers appreciable resistance to the flow of water. The smaller the pipe the greater is the resistance; and if the pipe size remains the same, a greater resistance is offered to a large flow than to a small one. The resistance to flow offered by a pipe can best be measured by the loss in pressure which results when water is forced through the pipe. If 100 feet of 2-inch pipe be fitted with a pressure gage at each end, and a stream of water be forced through that pipe, the gage at the outlet end will record less pressure than the gage at the inlet end. This loss of pressure measures the resistance offered by the 100 feet of 2-inch pipe to the flow of the quantity of water which was forced through. If the pipe were 200 feet long, the differ-

ence between the gage readings would be twice as great. No simple proportion exists between the loss in pressure and the quantity of water.

TABLE 1

PRESSURE LOSSES IN POUNDS PER SQUARE INCH FOR 100 FEET OF COMMON IRON PIPE OF VARYING DIAMETERS AND FOR VARYING FLOWS

Gallons per minute	Pipe sizes in inches											
	¾	1	1¼	1½	2	2½	3	3½	4	5	6	7
5	4.55	1.40	0.36									
6	6.35	1.97	0.52									
8	10.82	3.38	0.69	0.41								
10	16.45	5.06	0.89	0.62	0.22							
12		7.10	1.86	0.87	0.31							
14		9.52	2.47	1.16	0.41	0.14						
16		12.10	3.16	1.47	0.52	0.18						
18			3.94	1.83	0.64	0.22						
20			4.80	2.25	0.78	0.26	0.10					
25			7.18	3.38	1.18	0.40	0.16					
30			10.16	4.75	1.66	0.56	0.23					
35				6.36	2.21	0.74	0.31	0.14				
40				8.13	2.85	0.95	0.39	0.17				
45				10.00	3.55	1.19	0.50	0.22				
50					4.29	1.43	0.60	0.26	0.15			
60					6.02	2.01	0.85	0.38	0.20			
70					7.96	2.68	1.11	0.48	0.27	0.09		
80					10.25	3.42	1.42	0.63	0.35	0.12		
90						4.25	1.76	0.78	0.43	0.15		
100						5.51	2.15	0.96	0.53	0.18		
120						7.28	3.06	1.34	0.74	0.25	0.10	
140						9.68	3.98	1.82	0.99	0.33	0.13	
160							5.10	2.27	1.26	0.42	0.17	
180							6.40	2.72	1.56	0.53	0.20	
200							7.70	3.33	1.91	0.64	0.24	0.12
220							9.20	4.15	2.25	0.76	0.39	0.14
240								5.02	2.68	0.90	0.36	0.17
260								5.78	3.12	1.04	0.41	0.20
280								6.54	3.55	1.20	0.47	0.23
300								7.70	4.03	1.36	0.55	0.37
350								9.70	5.59	1.81	0.73	0.35
400									6.91	2.34	0.91	0.44
450									8.58	2.90	1.09	0.54
500									10.40	3.51	1.37	0.65

Table 1 is computed from results of experiments compiled by Williams and Hazen (Williams, Gardner, S., and Allen Hazen. Hydraulic tables. 3rd ed., revised, *115 p.* John Wiley and Sons, Inc., New York).

A value of 100 has been chosen for the "C" used in the computations indicated in the table above. The use of this value results in an indicated friction loss equivalent to the loss in ordinary iron pipe which has been in service for 10 years. Galvanized iron pipe probably deteriorates less rapidly than common iron pipe. The friction losses, as given in table 1, are probably greater than would be expected in galvanized iron pipe 10 years in service.

Many engineers have endeavored to determine the pressure losses resulting when certain sizes of pipe are used to convey varying quantities of water. Tables have been prepared from numerous experiments by which it is possible to foretell with some degree of exactness what losses in pressure may be anticipated under given

conditions of diameter of pipe, length of pipes, and quantity of water. Table 1 shows the pressure consumed by 100 feet of common iron pipe of varying sizes when varying quantities of water, measured in gallons per minute, are discharged. The loss resulting from other lengths can be obtained by multiplying the loss as given for 100 feet by the length of the line in question, divided by 100.

The use of table 1 makes it possible to compute the pressure required to force any flow of water through a line of any length and diameter. For instance, if a flow of 60 gallons per minute is to be forced through a 2-inch line 300 feet long, a pressure of 18.06 pounds per square inch would be consumed in overcoming the resistance to flow offered by such conditions. If the water is to be delivered at the outlet under a pressure of 20 pounds per square inch, an initial pressure of 38.06 pounds per square inch would be necessary.

In designing sprinkler layouts, the problem becomes more complicated, for in the main pipe line the quantity is being constantly decreased as the laterals are reached. And in the laterals, the flow is being constantly reduced as successive sprinkler heads are supplied. The pipe connecting the last two sprinkler heads on a lateral should be only large enough to carry the quantity required for a single head. The section between the main and the first sprinkler must carry the whole flow necessary for the lateral.

There is no short cut toward the intelligent design of such installation. Each lateral must be considered in turn, usually starting with the one most distantly removed from the source of water and pressure. Pipe sizes are determined for each section between successive sprinkler heads. If a manufacturer recommends, for the sprinkler head made by him, a working pressure of 15 pounds per square inch then the pressure at the foot of the stand must be enough in excess of 15 pounds per square inch to lift the water to the top of the stand and deliver it at the required pressure. One pound per square inch represents the pressure exerted by a column of water 2.31 feet high. If a stand is 12 feet high, the pressure at the base of the stand must exceed the required pressure for the operation of the head by 12 divided by 2.31, or 5.2 pounds per square inch. A pressure of 20.2 pounds per square inch, as measured on a gage at the foot of the stand, would be required before satisfactory operation could be secured.

The pipe joining this last stand in the example given above with the one next to it must be large enough to deliver the quantity of water required by a single head through the length of pipe represented by the distance separating the stands, and must provide a pressure of 20.2 pounds per square inch at the end of the line. The

next section must be similarly determined. In this case, the quantity required for two heads must be considered, since the last head and the next to the last must be supplied.

The pipe section leading from the main to the first sprinkler on a line must be large enough to deliver the entire flow for the lateral. The pressure requirement at the intake of this lateral must be smaller than that which is available at the source, since there is necessarily some loss of pressure in the main connecting the source of water with the head of the lateral.

Table 2 has been prepared as an aid in the determinations indicated above. Certain hypothetical conditions of pressure requirements and capacities of sprinkler heads have been assumed and possible combinations of pipe sizes computed. The pressure required at the intake of laterals made up of the indicated pipe lengths and carrying a certain number of sprinkler heads is also given under the heading "Initial Pressure."

Table 2 can be used only as a rough guide to required pipe sizes, and then only if the distance between sprinklers and the capacities and pressure requirements are as given.

A main designed to supply sufficient pressure for the most remote lateral is usually large enough to supply sufficient pressure for nearer ones. Ordinarily smaller pipe sizes can be used in laterals close to the source than in those more distant. Effort spent in a close determination of pipe sizes, so that every pound of available pressure is utilized, is repaid by a smoothly operating system and low first cost.

The design of a system for the use of portable stands is less complicated than that for a permanent installation. However, the same principles apply and the same care should be used. The greatest saving can be gained through the careful design of the main line, since small reductions in diameters of large sizes are reflected in relatively large reduction in costs per foot of pipe. The principles involved in designing the underground distributing main are, of course, common to all types of sprinkling installations.

DEVELOPMENT OF PRESSURE FOR SPRINKLER OPERATION

In some limited areas irrigation water is delivered through pipe lines under such natural pressure that sprinkler installations can be operated without the use of pumps. Such conditions, however, are not often found. Growers receiving water from gravity ditches or low pressure pipe lines, and those who secure water from private wells must use pumps to supply the pressure necessary for sprinkler

TABLE 2

SUGGESTED COMBINATIONS OF PIPE SIZES FOR USE UNDER VARIOUS CONDITIONS OF PRESSURES AND SPRINKLER CAPACITIES

Number of sprinklers 48 feet apart on line	Pressure required at sprinkler head, pounds per square inch	Discharge from single head in G. P. M.*															
		3 G. P. M.					7 G. P. M.					10 G. P. M.					
		Suggested lengths in feet for pipes of various sizes				Initial pressure,† pounds per square inch	Suggested lengths in feet for pipes of various sizes				Initial pressure,† pounds per square inch	Suggested lengths in feet for pipes of various sizes					Initial pressure,† pounds per square inch
		¾ in.	1 in.	1¼ in.	1½ in.		1 in.	1¼ in.	1½ in.	2 in.		1 in.	1¼ in.	1½ in.	2 in.	2½ in.	
3	15	144				25.5	144				30.0	96	48				31.0
	20	144				30.5	144				35.0	96	48				36.0
	25	144				35.5	96	48			33.4	48	96				34.7
	30	96	48			35.8	48	96			35.0	0	144				37.7
4	15	144	48			26.6	96	96			28.3	48	96	48			33.0
	20	96	96			29.2	48	144			29.3	48	48	96			29.7
	25	96	96			34.4	48	144			34.3	48	48	96			34.7
	30	48	144			37.1		192			38.3	0	96	96			37.7
5	15	144	96			30.4	96	96	48		29.6		144	48	48		27.6
	20	144	96			35.4	96	96	48		34.6		96	96	48		30.9
	25	96	144			32.0	48	144	48		36.0		96	96	48		35.9
	30	96	144			36.0	48	96	96		39.2		48	144	48		39.8
6	15		96	192		25.2	48	96	96	48	26.2		144	48	96		31.0
	20		144	144		27.5	48	96	48	96	29.5		96	96	96		32.7
	25		192	96		30.9	48	48	48	144	32.0		144		48	96	35.1
	30		240	48		35.2		96	48	144	36.2		96	48	48	96	36.8
7	15		96	96	144	28.3	96	96	96	48	32.4	48	48	96	144		30.5
	20		96	96	144	33.3	96	96	96	48	37.4	48	48	96	144		35.5
	25			192	144	35.7	48	96	144	48	37.3	48	48	48	48	96	38.4
	30			192	144	40.7	48	96	144	48	42.3	48	48	96	48	96	46.9

* G. P. M.=gallons per minute. † Pressure at the intake of the lateral carrying the sprinklers.

operation. The cost of pumps, in such cases, must be charged against the sprinkler installation, and the annual operation cost, including interest and depreciation, charged against the maintenance of the system.

When a pump is required one of the high pressure types should be chosen, since the pressure at the intake must be sufficient to overcome frictional resistance in the system in addition to the pressure required for the operation of the sprinkler outlets. Two types of pumps are in common use for this purpose, viz., displacement, or plunger, and centrifugal pumps.

Displacement pumps are those which force water by means of a piston or plunger traveling backward and forward in a close-fitting cylinder. Such pumps are divided into several classes, depending upon the number of cylinders built into a single pump and upon the action of the cylinders. A single acting plunger forces water only on one stroke of the piston; a double acting plunger forces water during both the forward and the backward stroke. All displacement pumps should be equipped with ample air chambers to act as cushions for absorbing pulsations due to the action of the pistons. A relief valve or by-pass should be placed in the discharge pipe to prevent damage to the pump or motor, should the discharge be shut off during the operation of the pump.

Displacement pumps for sprinkler operation should be chosen only upon recommendation by reliable manufacturers of pumping machinery. For certain conditions, such as an extremely high lift and delivery at high pressures, displacement pumps are well suited. Displacement pumps cannot be used with waters carrying sand.

Centrifugal pumps are rapidly gaining favor as sources of pressure for sprinkler operation. When such a pump is used, the outlets can be completely closed during the operation of the pump without damage. Centrifugal pumps create pressure by forcing water into a line by means of an impeller or vaned wheel which revolves at a high speed in a closed shell or case. A single-stage centrifugal pump, that is, a pump which carries but one impeller, may be used for installations where the required pressure at the intake need not exceed 50 pounds per square inch. In cases where a greater initial pressure is required, a two-stage pump may be used. A two-stage pump contains two impellers, each operating in a separate shell but rotated by the same shaft.

Centrifugal pumps must be installed close to the source of water. Long suction pipes should be avoided whenever possible. In cases where a centrifugal pump must be placed directly over a water

supply, as in a well, the distance from the water level during the period of greatest draw-down, to the center line of the pump must not exceed 22 feet. All centrifugal pumps must be primed before starting. This can best be accomplished by filling the suction pipe and pump shell by means of a priming pump located at the highest point on the pump's shell. Figure 12 shows a direct connected single-stage centrifugal pump used for the development of pressure for sprinkler operation.

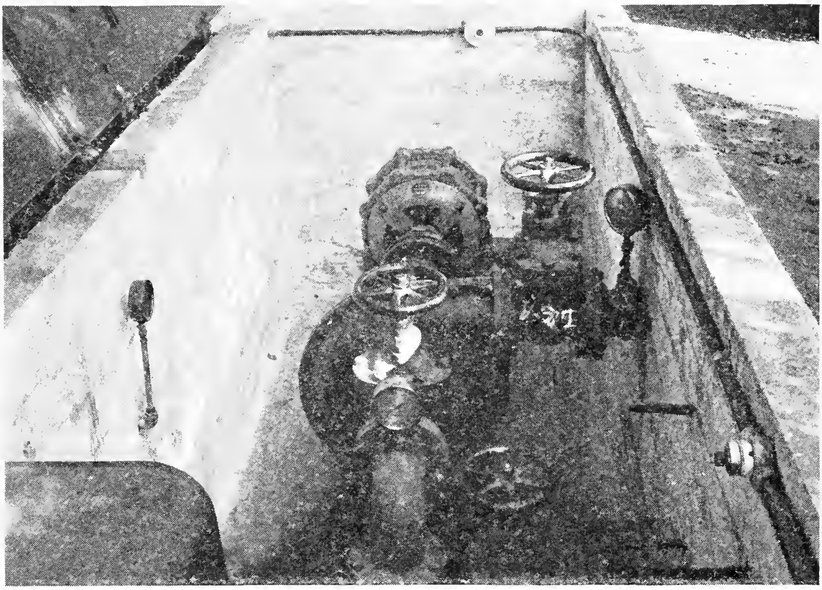

Fig. 12.—A typical pumping plant for sprinkler operation. Such pumping plants are necessary when the water supply is not under pressure or when available pressure is inadequate.

Centrifugal pumps are simple in design. They are inexpensive in first cost, as compared with displacement pumps of the same capacities. They have few wearing parts and are usually equipped with adequate oiling facilities. The better pumps are so assembled that replacements may easily be made.

The selection of the proper type of centrifugal pump and the proper size for a particular installation demands expert advice. The efficiency to be gained by a centrifugal pump under any set of conditions depends greatly upon the speed at which it is operated. Recommendations with regard to the speed of operation should be carefully observed.

POWER REQUIREMENTS FOR SPRINKLER OPERATION

The power required by any pumping plant depends upon the quantity of water lifted in a given time, the height to which it must be lifted, or the pressure required at the discharge, and the efficiency of the plant.

A simple formula for determining the horsepower required for lifting certain quantities of water to given heights is:

$$H.P. = \frac{G.P.M \times H \times 100}{3960 \times E} \qquad (1)$$

where $G.P.M.$ = quantity of water lifted in gallons per minute.
H = vertical lift effected, in feet.
E = expected combined efficiency of pump and motor. (About 65 per cent for well designed centrifugal plants driven by electric motors.)
$H.P.$ = horsepower required.

Since causing a stream of water to flow under a pressure of one pound per square inch requires as much power as would be expended in lifting the same stream to a height of 2.31 feet, the equation may also be written:

$$H.P. = \frac{G.P.M. \times P \times 100}{1714 \times E} \qquad (2)$$

where P = pressure in pounds per square inch which must be effected at the discharge end of the pump.

In cases where the same pump is used to lift water through appreciable distances, as from a well, and to subject the discharge to a pressure sufficient to operate a sprinkler system, the motor must be large enough to satisfy both these demands for power. Such computations can best be made by changing the pressure requirements into the equivalent feet of vertical lift (by multiplying by 2.31) and adding the vertical lift to the point to which pressure requirements are computed. The relation stated in equation (1) can then be used. In cases where a long suction pipe is necessary, allowances should be made for losses in efficiency due to the resistance to flow in the suction pipe.

THE EFFECTIVENESS OF IRRIGATION BY SPRINKLING

PENETRATION AND SOIL MOISTURE CONSIDERATIONS

The value of overhead sprinkling as a means of irrigation depends upon the effectiveness of this method in creating and maintaining a satisfactory soil moisture content. Soils vary in water holding capacity and permeability, fine-textured soils holding more moisture than coarser soils but "taking" water less readily. Plants suffer for water when the moisture content within the rooting zone drops below a point known as the wilting coefficient. The wilting coefficient for most soils may be determined in the laboratory with a fair degree of accuracy. If it can be assumed that the major concentration of feeding roots occurs in a definite soil stratum, a satisfactory method of irrigation would permit the application of water by such a means and in such an amount that the soil moisture content in that stratum of soil may be maintained between these limits.

Six sprinkled citrus groves in Los Angeles and Orange counties were sampled intensively for depth of penetration of irrigation water and soil moisture content during the irrigation season of 1925 to determine the effectiveness of irrigation by the sprinkling method. Three of these groves were on decomposed granite soils of low water holding capacity and easy permeability, while three were on soils of finer texture into which water penetrates less readily. In most cases the groves were sampled immediately before and after each irrigation. In every case samples were taken from the same limited areas at each time of sampling. Although this method of sampling did not necessarily indicate the average moisture content in the entire grove at the time of the sampling, it did give a fairly accurate idea of the soil moisture history in the small plots under consideration.

In the case of the three groves on decomposed granite soils, the sampling indicated that satisfactory irrigations had been accomplished. In none of these groves did the soil moisture content in the principal rooting zone fall below the wilting coefficient between March and November. Adequate penetration of moisture at each irrigation was, in most cases, indicated by an increase in soil moisture content in the fourth foot of soil. The effect of irrigation was sometimes evident in the fifth and sixth foot. It is to be noted that these groves were managed by men experienced in sprinkler operation. Sprinkler heads were well adapted to conditions, and factors determining the required period of operation were well understood. A great measure

of the success of overhead sprinkling in these groves can probably be attributed to the experience of the operators.

Inadequate penetration of irrigation water was noted in each of the three sampled groves on the heavier soil. In most cases irrigation resulted in an increase in the moisture content of the surface foot alone, the greater depths being at, or dangerously near, the wilting coefficient when the residual soil moisture from winter rains had been depleted by plant withdrawals. In one case, however, sprinklers were operated for a period four times as long as usual and an increase in the soil moisture content was noted to a depth of six feet. This fact together with scattered observations upon the penetration secured in difficult soils by overhead sprinklers in other areas seems to indicate that adequate penetration in such soils can be obtained with experience, patience, and proper care in the selection and use of equipment.

DUTY OF WATER

Observations on the amount of water used per acre in the irrigation of citrus trees by overhead sprinkling as compared with the amount used by other methods show no significant difference which can be attributed to the method of application. These observations were localized in three areas. In these areas the amount of water used in 1925 on groves under good sprinkler management were compared with neighboring groves of comparable age, variety, and thrift, which were irrigated by means of furrows. The results of these observations are summarized in table 3. Although it is impossible to draw conclusions from such a small number of fields, it is probable that in practice, such factors as the cost of water used, the skill of the irrigator—and in the case of surface irrigation, the preparation of the land—are of more importance in determining the amount of water to be used per acre than is the method of application.

EVAPORATION LOSSES

Losses by evaporation from overhead sprinkling, especially during periods of high temperatures and low humidity, are doubtlessly significant in areas where water costs are high. As yet, no workable means of measuring this loss has been devised. Irrigating by sprinklers at night seems to reduce the losses from evaporation.

TABLE 3

DUTY OF WATER IN ACRE-FEET PER ACRE ON SPRINKLED AND FURROW IRRIGATED ORANGE GROVES, SEASON 1925

Area	Soil type	Sprinkled groves	Areas in acres	Use of water in acre-feet per acre	Weighted average	Furrow irrigated groves	Areas in acres	Use of water in acre-feet per acre	Weighted average
Sunnyslope	Hanford gravelly sandy loam.	1	8.5	1.13	1.13	1	4.5	1.14	1.67
						2	4.5	1.54	
						3	4.5	1.75	
						4	10.0	1.92	
						5	10.0	1.64	
						6	10.0	1.71	
Sierra Madre	Hanford gravelly sandy loam.	1	8.7	1.88		1	5.50	1.42	
		2	5.0	1.26	1.28	2	4.00	1.31	1.38
		3	23.0	1.05		3	3.90	1.40	
La Canada	Hanford gravelly sandy loam.	1	8.5	1.11	1.11	1	10.0	1.00	1.00

FERTILIZER DISTRIBUTION

Although conclusive experimental work is lacking, it can probably be assumed that the distribution of fertilizing materials through the soil after a surface application may be accomplished more speedily and more effectively by sprinkling immediately after the distribution of fertilizer than by any other means except a natural rain of proper intensity and duration.

PEST AND DISEASE CONTROL

Experimental evidence as to effectiveness of overhead sprinkling upon pest and disease control is not available.

TEMPERATURE AMELIORATION

In areas affected by hot dry winds, relief from excessive drying out can probably be attained by sprinkling during the hours of greatest danger, since exaporating water absorbs heat. An additional benefit would accrue from the increased humidity in the area under the sprinklers. In areas endangered by low temperatures, sprinkling as a means of frost protection is of doubtful value. In freezes of long duration, the ice load carried by delicate trees, when sprinkling is unwisely attempted, may, and often does, cause damage to the trees.

FRUIT QUALITY

Experienced packing house managers claim that fruit of a higher quality comes from sprinkled groves than from groves irrigated by other means. It has never been proved, however, that the increased quality is due to the method of irrigation.

SUMMARY

1. Irrigation by overhead sprinkling is costly. At present this method of irrigating is limited to the production of high-priced crops on land of high value.

2. Intensive soil-moisture sampling during the irrigation season of 1925 indicated that adequate soil-moisture penetration can be secured by the sprinkling of decomposed granite and sandy loam soils if the sprinkling equipment is wisely selected and intelligently operated. Experimental evidence as to the adaptability of sprinkling to heavy soils is not as conclusive.

3. The type of installation to be adopted for a particular location depends upon the crops to be irrigated, the money available for investment in such equipment, and the labor available during the irrigation.

4. The detailed design of a sprinkler layout requires considerable skill and care.

5. Except in favored localities where natural pressure is available, pumps must be installed to create pressure for the operation of the system.

6. Sprinkler systems, if used, should be installed because of their ability to distribute irrigation water uniformly and effectively, and not because of claims for other advantages.

7. Judgment and care are essential in the intelligent operation of a sprinkler system. There is no substitute for a soil auger in determining the effectiveness of an irrigation.

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